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PREDICTING EFFECTS ON FISH OF FIRE RETARDANTS IN STREAMS

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ABSTRACT

Reports a first attempt to provide a computation system that will permit a rapid estimate of the amount of hazard to game fish caused by release of fire retardant chemical into streams. Field measurements necessary for application of the system are (1) the amount of retardant (pounds, nitrogen, calculated as NH_3) that enters a stream and (2) the discharge rate and average velocity of the stream, both measured at or near the point of retardant introduction. The result is an estimate of the time, or distance, necessary to allow dilution of the pollutant by shear and turbulent mixing to produce nonlethal conditions. Accuracy expected is about plus or minus 75 percent of the result. Despite a large uncertainty, the estimate is valuable and useful. Causes of this uncertainty are discussed and sample computations are presented using U.S. Geological Survey data for several western Montana streams.

INTRODUCTION

In recent years, fire retardant materials applied by aircraft have become important in the control of range and forest fires. The number of fire retardant drop missions flown rose from virtually zero in the mid-1950's to nearly 15,000 in 1971 and involved some 17 million gallons of material (assuming an average drop of 1,100 gallons). Use of sodium calcium borate was discontinued in the early 1960's because it was heavy, expensive, and a soil sterilant. More effective retardant salts, ammonium phosphates and sulfates, have been used for more than a decade. In general, they are fertilizers and produce beneficial results unless a dosage is too heavy.

Wildfires may occur in areas where lakes and flowing streams contain valuable game fish. Fire retardants are concentrated aqueous solutions of chemical materials. Since at some concentration, most soluble chemicals will injure or kill fish, the possibility of damage to fish exists because retardants can be dropped directly into the body of water in which they live.

The purpose of this report is to provide a method of estimating whether fish kill is likely to result from a particular release of retardant. The approximate length of the affected zone of a stream can be calculated. Accuracy of the result is expected to range between plus or minus 75 percent, which is not precise, but can be of considerable value. This figure is the result of estimating the probable uncertainty of each item or source of data required for a computation, and then tracing the cumulative effect of these uncertainty values through the computation procedure outlined in this report. Where two or more values are combined or interact arithmetically, the uncertainty of the result is identified by finding the square root of the sum of the squares of the individual uncertainties of the values being combined.

It would be important to know, for example, whether a given event would be likely to damage only a few hundred feet of a stream or its length to the next major confluence. The estimation system would make possible a judgment before the drop mission is ordered as to whether the immediate fire control need is great enough to warrant possible consequences. Preseason determination of stream discharge rates and velocities would make potential damage appraisal a simple matter.

There are two main reasons for the low level of accuracy: (1) studies using fire retardant materials approved by the USDA Forest Service show that the toxicity of the neutral ammonia molecule is related to the species and age of the fish and to a variety of such minor constituents of commercial retardant preparations as corrosion and spoilage inhibitors and thickeners and (2) extensive, careful data on the flow characteristics of the stream will not be available.

Many stream gaging stations are maintained by various agencies, and readings are taken daily at some. However, only a few streams--perhaps a hundred or so in the whole United States--have been studied by using dye tracers to allow calculation of the discharge rate and mean velocity at any desired point from data collected routinely at an index gage station. Thus, a field approximation of flow characteristics will generally have to suffice. Also, at this point, we can only assume that the diffusion characteristics of fire retardant solutions or slurries are similar to those of dyes used in the referenced experiments. We have not explored the possibility of significant differences.

Most fire retardants now in use contain diammonium phosphate $((NH_4)_2HPO_4)$, monoammonium phosphate $(NH_4H_2PO_4)$, ammonium polyphosphate or ammonium sulfate $((NH_4)_2SO_4)$ as the active ingredient. Other components provide thickening, inhibit bacterial spoilage, control corrosion of aircraft structures, and provide color for visibility. Of these substances, the one that is the limiting factor for fish poisoning is the ammonium portion of the active fire retardant material (McKee and Wolf 1963). Therefore, calculations described are based on the number of pounds of nitrogen placed into the water, calculated as pounds of ammonia, NH_3. The neutral, molecular form of ammonia, NH_3, is the active entity. The acidity of the solution (pH) controls the balance of the ammonia between NH_3 and the ammonium ion, NH_4^+. Allowance for this factor is made in the computation procedure.

PREVIOUS STUDIES

A few streams have been studied in detail in a way that has provided a method of predicting the behavior of contaminants. The Monocacy River in Maryland is a prime example of such a study (Taylor 1970). The probable use for this kind of a stream analysis system is related to the use of stream water for municipal supplies. If, for example, a truckload of soluble contaminant is spilled into the stream, both the time of arrival and the duration of contamination at the system intake can be predicted. As applied to fire retardant operations, the system will allow prediction of the time and distance a contaminant must travel to be sufficiently diluted to avoid fish fatalities.

The stream analysis employed by Taylor on the Monocacy River involved the introduction at one point in the stream of a soluble "slug" of fluorescent dye. At each of several downstream locations, measurements were made of (1) dye concentration at appropriately spaced times (15 minutes to several hours) and (2) stream discharge, as measured by a current meter.

The discharge rate was also monitored continuously at some one index gaging point to permit corrections for changes during the experiment. These measurements permit calculation of the discharge rate, Q, and the mean velocity, $\bar{v}$. The discharge rate is the number of cubic feet per second of water flowing past a point, or through an imaginary plane perpendicular to the direction of flow. The mean velocity equals the discharge rate Q divided by the area in square feet of the cross section of the stream (the area of the plane between water surface and streambed).

In reducing the data to useful form, the concentrations at each sampling point were plotted against time. Plotting produced a graph that rises rapidly to a rounded peak, then decreases with some tailing toward zero. By using the known Q for that sampling point and the integrated area under the curve, the quantity of dye passing that point was calculated. Some loss occurred from adsorption on streambed material and vegetation, from chemical change of the dye, and perhaps from other more obscure causes. If the original amount of dye introduced is known, it is possible to correct for this loss by increasing the observed concentrations to represent a totally conservative dye. A conservative solute would be the idealized case where no dye is lost to solid surfaces over which the solution flows.

Numerous tests on the same stream conducted at different discharges and with different quantities of dye are not readily comparable as both factors determine the magnitutude of observed dye concentrations. A method developed by the U.S. Geological Survey (Kilpatrick and others 1970) provides a means of comparing and analyzing dispersion effects existing for different streams. In the Monocacy River study, Kilpatrick developed and Taylor used the concept of unit concentration, particularly as applied to maximum concentration peaks. Unit concentration, C_u, was computed for each sampling point according to:

$$C_u = (\text{conservative concentration, mg/l}) \frac{(\text{Q, cfs})}{(\text{amount introduced in lb})} \tag{1}$$

The concentration and the discharge rate were those measured at a given sampling point at the same time. The original amount introduced was the same for all sampling points and all times.

The time required for the concentration peak to reach any particular sampling point, measured from the instant that dye was introduced, was called the lapsed time, T_L. It was determined by noting the position of the peak-concentration-versus-time graph for each sampling point.

A graph of C_u versus T_L has the general appearance of figure 1, being approximately parallel to the lines shown. For any one stream, the position of the line is a function of the longitudinal dispersion, which is logarithmically related to the discharge rate and, therefore, to the mean velocity. Comparison of different streams showed that where $\bar{v}$ is relatively small (mixing is relatively good) the C_u versus T_L line has a steep slope (fig. 1). The slope chosen was thus conservative, implying that concentration will be decreased at least to the indicated value or further.

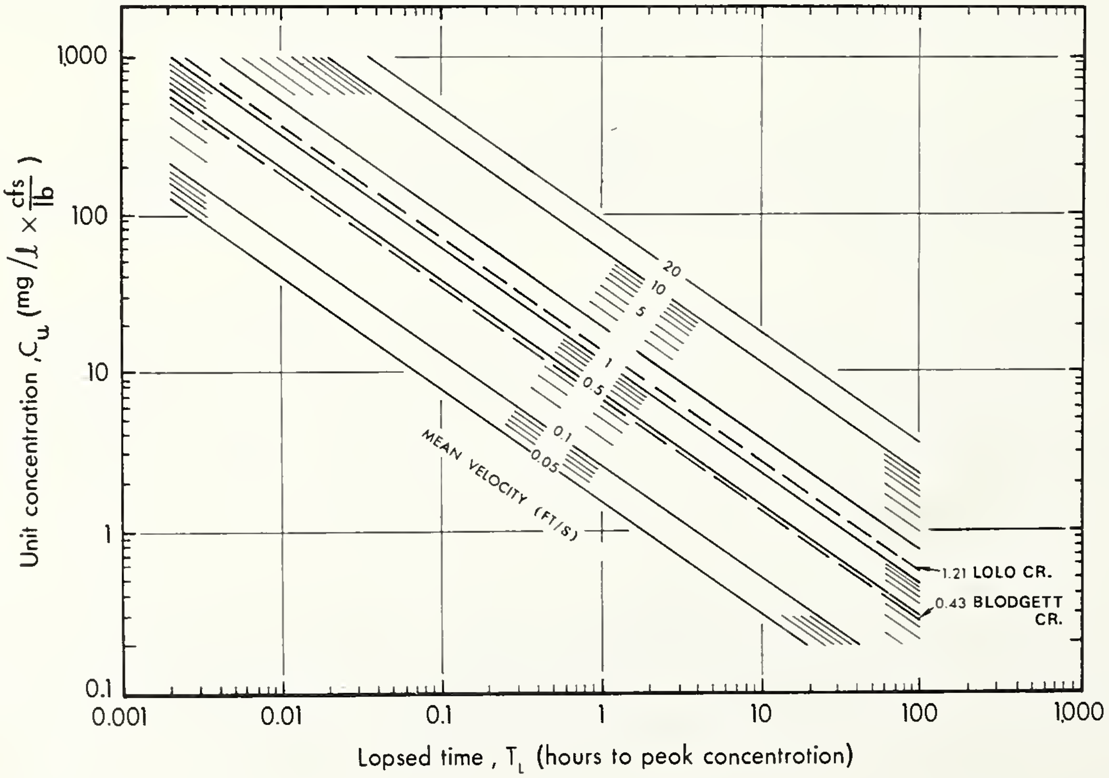


Figure 1.--Unit concentration curves describe the interaction of stream discharge rate and average stream velocity in decreasing peak concentration of the introduced contaminant with time. Curves apply only after complete lateral and vertical mixing.

DISPERSION OF SOLUBLE MATERIALS IN STREAMS

The diluting effect we are interested in depends on the mixing that moves contaminants laterally (across the stream) and vertically, as well as longitudinally (elongating in downstream direction), into volumes of uncontaminated water. Generally, the greater the mean velocity of a stream, the less will be the longitudinal mixing per unit of distance traveled. There are exceptions, since stream geometry also is a factor in determining longitudinal dispersion. A lower velocity will permit turbulent eddies to have a greater effect on the concentration of the contaminant. Lateral and vertical mixing are reached quickly in a stream, but longitudinal mixing (dispersion) continues as long as there is a stream. Always, there will be a gradient of velocity from the line of maximum velocity (just below the surface near channel center) to the line of minimum velocity at bank or bottom surfaces. This gradient causes a shearing phenomenon that contributes largely to longitudinal mixing. Volumes at the channel center move ahead of volumes nearer the banks and bottom.

When a flowing stream acts on a slug of soluble contaminant, the general pattern of events will fit somewhere along a spectrum of possibilities.

If the stream is very large, and the quantity of contaminant not too large, the material will be diluted to harmless levels relatively quickly. If the stream is reasonably large, some zone of probable fish fatalities may exist, but the dilution will occur soon and the contaminated volume will still be small; so exposure time at any point will be short. This means that fairly high concentrations can be tolerated by fish. If the stream is small, dye concentration will remain high for longer distances or times; consequently, the peak will be more spread out, and exposure times longer. Because of this, dilution must continue over greater distances before the combination of concentration and exposure time become tolerable to fish. If the stream is quite small, intolerable conditions may prevail until tributaries significantly add to the discharge and provide the needed dilution.

APPLICATION TO RETARDANT OPERATIONS

In figure 1, the location of a working line for any given stream has been related for utility purposes to the mean velocity rather than to the discharge rate. This approach seems to agree with available data (Taylor 1970) and is more directly associated with the mixing phenomenon. Also, for practical purposes, $\bar{v}$ entails a much smaller range of values than Q (0 to about 5 or 10 feet per second compared to 0 to about 50,000 cubic feet per second).

In addition to the C_u working lines of figure 1, three other graphs are needed. The first (fig. 2) provides knowledge of the length of time that fish will be exposed to the contaminant (exposure time (T_E) as a function of the lapsed time). Taylor's work on the Monocacy River was concerned with the interval during which the concentration might be high enough to represent an appreciable hazard to a drinking water supply. His arbitrary definition of the trailing edge of a peak was that point at which the concentration is 5 percent of the maximum concentration. As a premise for relating the calculating system to the survival of fish experiencing a slug of contaminant, it is reasonable to assume that if a particular fish makes it through the peak concentration, it is then likely to survive the whole event. Thus, an arbitrary choice has been made: exposure time is the length of time that the concentration of contaminant exceeds 50 percent of the peak concentration. Figure 2 is derived from this criterion as applied to time-concentration curves from the Monocacy River study (Taylor 1970).

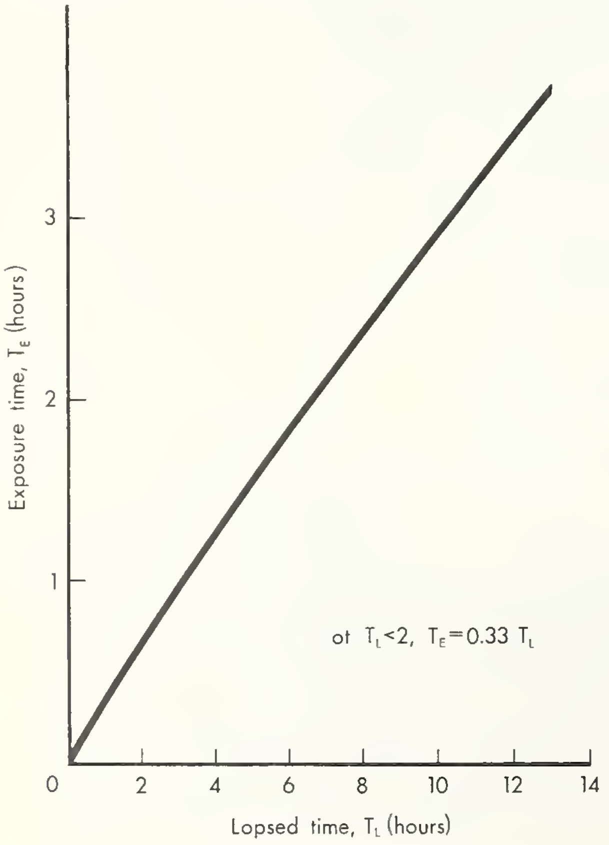


Figure 2.--Variation of length of exposure with time, following introduction of contaminant into stream. Exposure time is that period during which concentration is equal to or greater than 50 percent of the peak concentration at points fixed with respect to the terrain.

By this definition, exposure time is zero at the point where the contaminant is introduced. This definition cannot correctly describe the true situation because at the instant of application, a retardant dispersal pattern will contaminate the surface of perhaps several hundred feet of the stream. Thus, if vertical mixing occurs before the streamflow has moved the pattern very far, the exposure time could be larger temporarily than the corresponding lapsed time. A suitable correction for this effect could be made by using as a total exposure time the sum of the value obtained from figure 2 and the time required for the water to move a distance equal to the length of the original contamination zone. For the examples cited in this report, and probably for most other conceivable circumstances, use of this correction does not change the nature of decisions that might be reached concerning fire retardant operations.

During the time of exposure, T_E, concentration of the contaminent is not constant, but increases to a peak and then decreases. The best value of concentration to use in determining the tolerance time, T_T, is the integrated average concentration over the exposure interval. Using the areas above half-height (50 percent of peak concentration) of the conservative time-concentration curves of the Monocacy River study, the effective concentration, C_E, of the contaminant was found to be 0.83 times the peak concentration.

The next graph needed is one relating contaminant concentrations to the time, T_T, necessary for fatality to occur (fig. 3 or 4). The data of Blahm and others (1972) and of Herbert and Shurben (1964) have been used to determine what this graph should be like. Earlier data exists (McKee and Wolf 1963, p. 134), but few if any workers recorded the pH existing during their experiments.

In figures 3 and 4, the circled points are data from experiments using fingerling rainbow trout (hatchery-reared, Herts., England) and an added chemical, ammonium chloride. The pH was controlled at 7.8 by equilibrating the solution with prepared mixtures of air and carbon dioxide. The solid points are data from experiments using subyearling

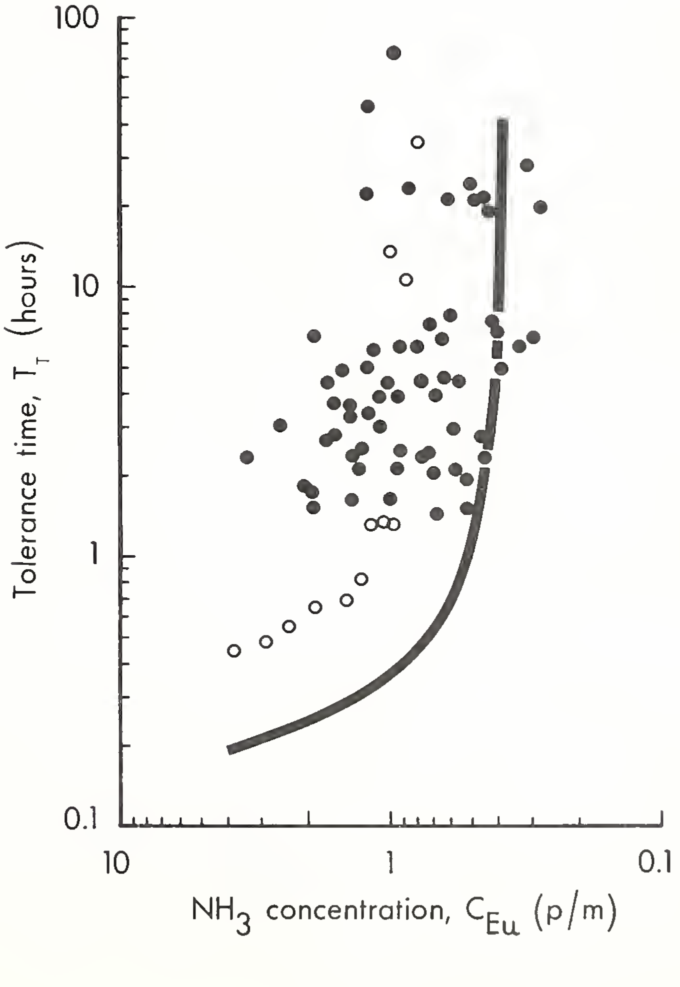


Figure 3.--Toxicity of ammonia to fish at the 10 percent mortality level. C_{Eu} *is the concentration of nonionized ammonia,* NH_3. *Circled points are data of Herbert and Shurben (1964); solid points are data of Blahm and others (1972).*

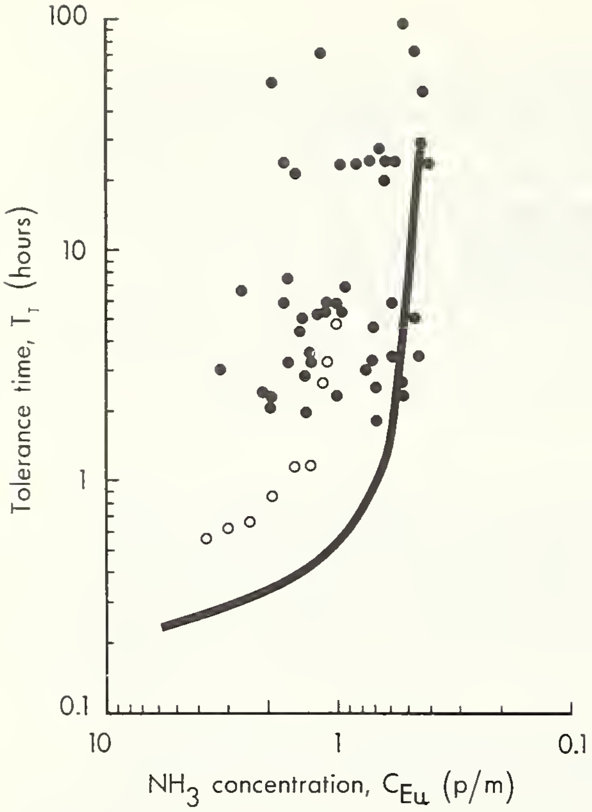


Figure 4.--Toxicity of ammonia to fish at the 50 percent mortality level. C_{Eu} is the concentration of nonionized ammonia, NH_3. Circled points are data of Herbert and Shurben (1964); solid points are data of Blahm and others (1972).

and yearling specimens of both rainbow trout and the coho salmon (hatchery-reared, Oregon). These fish were subjected to various concentrations of each of four different commercial fire retardant preparations. The pH of the solutions was not controlled, but it was measured during each experiment. For each data point in figures 3 and 4, the total concentration of ammonium compound(s) and the pH have been used to calculate the concentration of molecular (nonionized) NH_3.

The curvature of the graph at higher concentrations and lower times is certainly real. It is likely, though, that if Herbert and Shurben (1964) had used more than one species of fish and more than one type of contaminant, a scattering of data similar to that of Blahm and others (1972) would have been produced. Since it is clear that conditions will also fluctuate in field use, working curves in figures 3 and 4 approximate the "safe" edge of point distributions. This is to say that by using the curves, one can predict the worst possible consequence of a given event.

Another graph (fig. 5) facilitates computation of the nonionized NH_3 concentration from knowledge of the total concentrations of NH_3 and NH_4^+ and from the pH. From the ionization constant expression

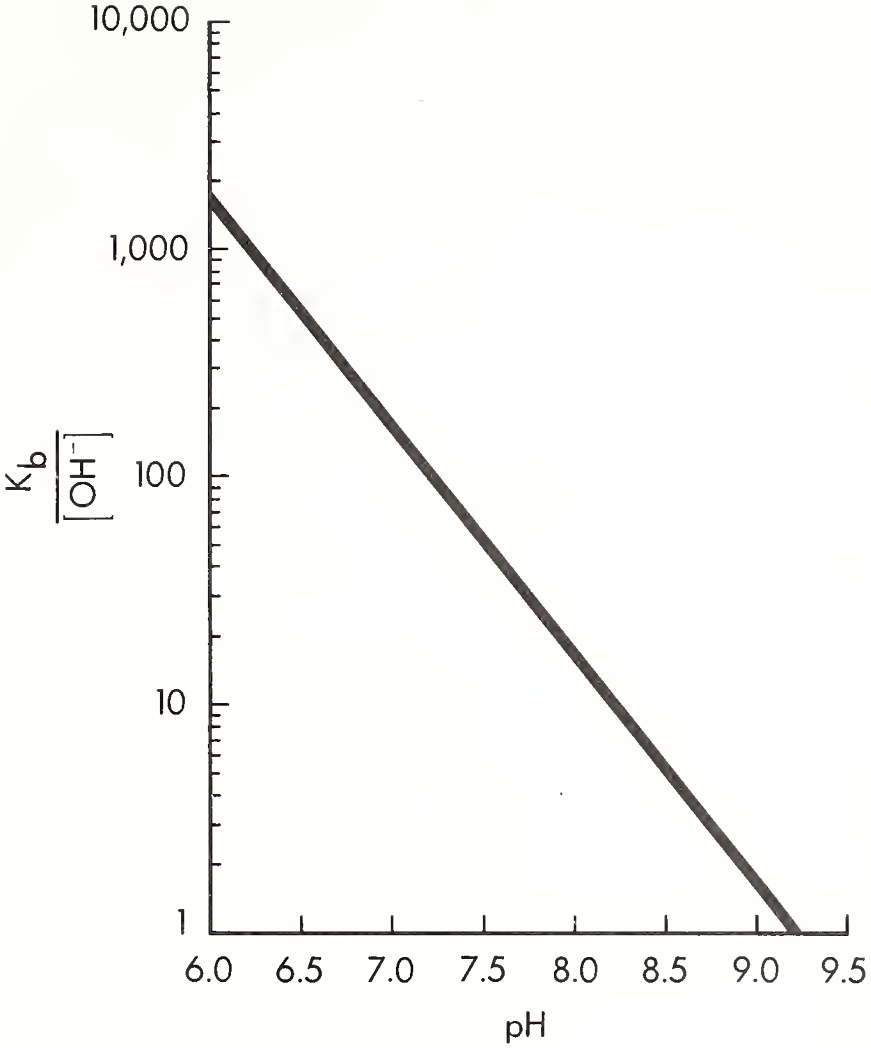
$$K_b = \frac{[NH_4^+]\ [OH^-]}{[NH_3]} = 1.8\times10^{-5}$$

and the fact that total ammonia nitrogen concentration = $[NH_4^+] + [NH_3]$, it follows that the concentration of nonionized NH_3 (hereafter called C_{Eu}) is

$$C_{Eu} = \frac{(\text{total concentration})}{1 + K_b/[OH^-]} \qquad (2)$$

The factor $K_b/[OH^-]$ is a simple logarithmic function of pH, and values for it are available from the graph in figure 5.

Figure 5.--A graph of the relation between $K_b/[OH^-]$ and pH, where $[OH^-]$ is the molarity of hydroxide ions in the solution and K_b is the ionization constant of ammonia, 1.8×10^{-5}.



SAMPLE COMPUTATIONS

The data presented in table 1 are from the files of the United States Geological Survey in Helena, Montana. They represent a range of stream sizes and the usual state of flow conditions during the fire season.

The approximate dimensions of the dispersal pattern produced on the ground by a 600-gallon retardant drop from usual altitudes (100 to 300 feet) have been established (MacPherson 1967). From a representative contour pattern of such a drop and by using the stream width in table 1, estimates can be made of the amount of retardant that might enter the water if the aircraft track is (1) parallel or (2) perpendicular to the stream (fig. 6). Such estimates are made by superimposing the dispersal pattern on a map of the stream. Summation of areas common to the stream and to each contour of retardant density yields the volume of retardant entering the stream. Knowledge of the concentration of total ammonia in the retardant mixture yields the quantity of ammonia that entered the stream.

Table 1.--*Selected data from United States Geological Survey gaging station records*

Station number	Location	Date	$\bar{v}$[1]	Q[2]	Area	Width
			$Ft\ s^{-1}$	$Ft^3\ s^{-1}$	Ft^2	Ft
12-3514	Eightmile Creek (Florence, Mont.)	8/27/63	1.12	4.9	4.35	9
12-3475	Blodgett Creek (Corvallis, Mont.)	8/26/68	.43	11.7	27.2	31
12-3520	Lolo Creek (above Sleeman Creek, Lolo, Mont.)	9/12/60	1.21	35.9	29.6	46
12-3400	Blackfoot River (Bonner, Mont.)	8/27/69	1.88	730.0	389.0	195

[1] Mean velocity

[2] The number of cubic feet per second of water flowing past a point, or through an imaginary plane perpendicular to the direction of flow.

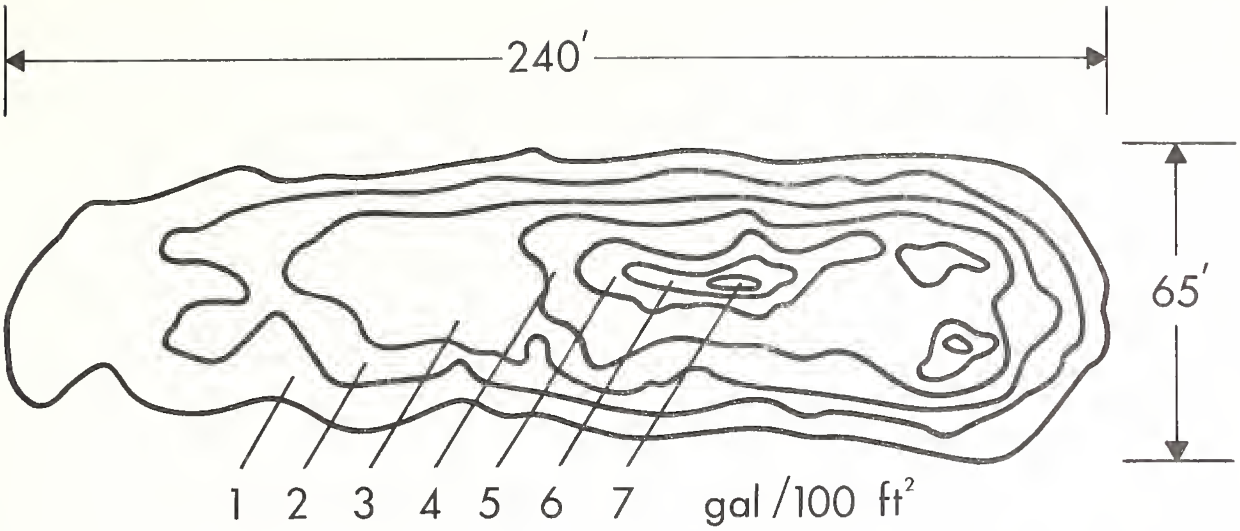


Figure 6.--A typical dispersal pattern. The diagram depicts results characteristic of the release of 600 gallons of retardant from an altitude of 100 to 300 feet.

Of course, concentration at the point of contamination is high. If it is great enough to produce a lethal zone, then lethal conditions will prevail only until the dilution has proceeded to a set of conditions we will call "critical." The distance the concentration peak is required to travel to reach that set of conditions is called "the critical distance." Beyond this point fish survival is likely.

The computation process begins with an assumption of the distance a concentration peak will travel downstream from the point of introduction. This assumption should be a first guess of the distance required to dilute the contaminant just to the critical condition. But, it is better to make the first assumed distance too long rather than too short, for several reasons. The process continues by using the assumed distance and the available data for discharge, Q, and the mean velocity, $\bar{v}$, to calculate lapsed time, T_L, and exposure time, T_E. Next, T_L and $\bar{v}$ are used to find the unit concentration, C_u, from figure 1. After estimating the amount of total ammonia that entered stream, C_u and Q can be used in equation (1) to find the conservative concentration, C_p. The effective concentration, C_E, is then 83 percent of C_p. The effective nonionized concentration is calculated from figure 5 and equation (2). The tolerance time, T_T, is then read from figure 3 or 4. T_T will turn out to be approximately equal to T_E when the chosen distance is equal to the critical distance.

The computation steps just described are presented below in their proper order. Their numerical and letter headings correlate with numerical examples and tables in following sections.

1. Acquire values (tabulated data or field measurement) for discharge, Q, mean velocity, $\bar{v}$, and pH.

2. Assume some distance of travel.

3. Compute exposure time, T_E.

   A. From $\bar{v}$ and distance find lapsed time, T_L.

$$T_L = \frac{\text{distance, ft}}{\bar{v}\text{, ft/s}} \left(\frac{1}{3{,}600 \text{ s/h}} \right) \text{h}$$

B. From T_L and figure 2 find T_E.

4. Compute tolerance time, T_T.

A. From T_L, $\bar{v}$, and figure 1 find the unit concentration, C_u.

B. Estimate the amount of NH_3 that entered the stream.

C. From C_u, Q, pounds NH_3, and equation (1), find the conservative concentration, C_p.

D. Compute the effective concentration, C_E.

$$C_E = 0.83\ C_p$$

E. From C_E, figure 5, and equation (2), find the effective nonionized concentration, C_{Eu}.

F. From C_{Eu} and figure 3 or 4, find T_T.

5. Calculate the ratio, T_E/T_T.

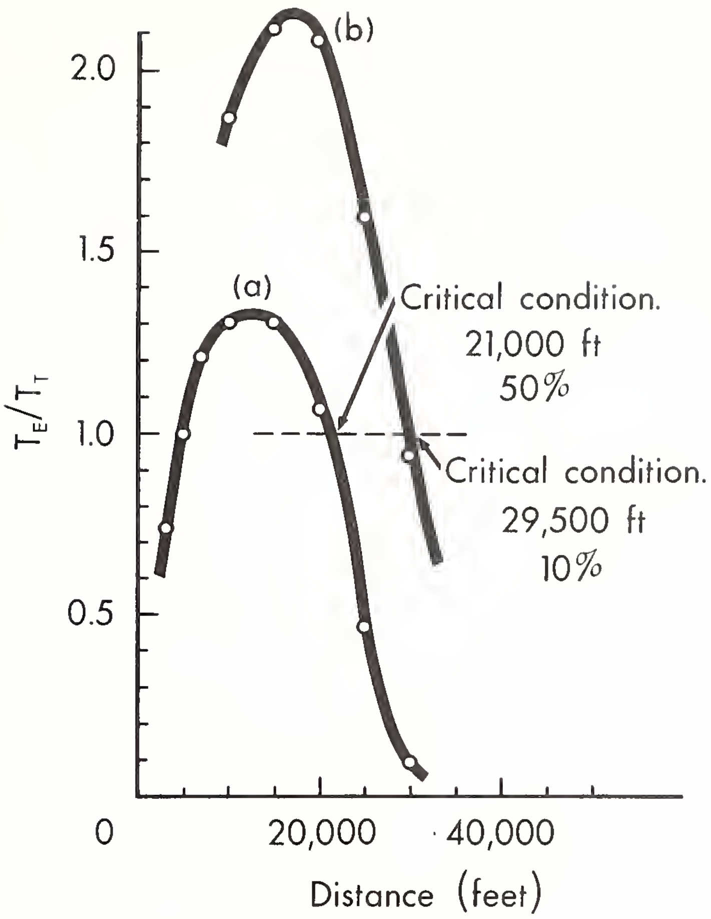
Repeat steps 2 through 5, choosing other values of distance, until critical conditions are reached.

If the original choice of distance was too long, then the ratio T_E/T_T will be less than 1.00. Choosing a somewhat shorter distance will produce a ratio closer to or perhaps greater than 1.00. Rather than a large number of repeated computation series, a graphical method of finding the critical distance would be the most efficient.

The example given presents this technique. The appendix shows the results of several computation series based on a hypothetical retardant drop over Lolo Creek with the aircraft track approximately parallel to the stream. The amount of NH_3 entering the stream is estimated at 111 pounds. Hydrologic data are real. If several values of T_E/T_T, bracketing the area where T_E/T_T = 1.00, are plotted against distance, as in figure 7, curve a (from 30,000 down to 15,000 feet), the intersection of the curve with the T_E/T_T = 1.00 ordinate locates the critical distance. In figure 7, curve b shows the effect of applying the C_{Eu} to the 10 percent mortality data of figure 3.

If further computation steps are carried out for shorter distance choices, the value of the ratio again falls below 1.00. This value could signify an actual zone in which fish would be likely to survive if, but only if, the contaminant were introduced as a very small volume of concentrated solution. Such a situation could produce an exposure time so brief at small lapsed times that the likelihood of survival is significant. However, usually in delivery by air tanker, the exposure time is significant even near the point of delivery. If a zone of lethal conditions exists at all, it probably begins at or very near the delivery point and persists downstream to the critical point.

Figure 7.--Ratio of exposure time to tolerance time as a function of distance traveled. A plot of the results of the sample computation using data on Lolo Creek (see appendix).



DISCUSSION

The Western Fisheries Ecology Station, Environmental Protection Agency, Corvallis, Oregon, recently joined with the Forest Service and the Bureau of Land Management in undertaking research to define water quality criteria needed to protect desirable freshwater fishes in the Pacific Northwest. Determination of fish survival in water containing various concentrations of fire retardant formulation is one part of their endeavor. Some early data provided by this effort are, in part, the basis for the toxicity curves in figures 3 and 4 of this report.

Clearly, the field data for a given application of this system are likely to be approximate. Stream conditions could be measured carefully at the introduction point soon after the event, but estimates, such as those for pH and mean annual low discharge values, will be used in many cases. The amount of ammonia involved will be accurately known only if the whole load enters the stream. In most instances, a judgment will have to be made, based on the overlap of the dispersion pattern intersecting the stream and the size of the aircraft load. Recognition of these factors and collection of the best possible data will be important to any use of the method. The expected accuracy of the estimate, plus or minus 75 percent of the result, reflects consideration of these factors.

The method described in this paper usually will be applied:

1. As a part of fire planning and fire suppression operations. This application allows for a before-the-fact decision as to whether or not to accept the result of knowingly applying retardant across a stream. In a critical firefighting situation, the immediate benefit might be worth it. Discharge rates and cross sections of streams could be predetermined and placed on maps for ready reference. These would be typical low water, fire season values for the streams chosen. The effect of a slug of contaminant at a given point would be calculated and a decision made, based on fishery importance and the fire situation.

2. As an assessment of the effects of an accidental release of fire retardant into a stream. This application would allow calculation of the zone in which damage to fish might be expected. The discharge rate and the cross section of the stream would be measured at or near the point of introduction, if such data were not already tabulated.

Fires can cause fish mortalities by increasing the temperature and ash content of streams and in other ways. This report offers a way of insuring that retardant materials are not blamed for effects they could not have produced.

The computation system described can be applied far more generally than might be apparent from the discussion of its application to fire retardants. It can be used to provide an estimate of the diluting action of a flowing stream on a given amount of any soluble material introduced essentially at one time and at one point on the stream.

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APPENDIX

SAMPLE COMPUTATIONS

LOLO CREEK - PARALLEL

1. $Q = 35.9\ ft^3/s$; $\bar{v} = 1.21\ ft/s$; pH = 8.0

2. Distance, ft	30,000	25,000	20,000	15,000
3. A. T_L, h	6.88	5.75	4.60	3.44
B. T_E, h	2.06	1.75	1.44	1.10
4. A. C_u, p/m ft^3/lb s	3.50	4.00	4.75	5.80
B. pounds NH_3	111.0	111.0	111.0	111.0
C. C_p, p/m	10.8	12.4	14.7	17.9
D. C_E, p/m	9.0	10.3	12.2	14.9
E. C_{Eu}, p/m	.47	.54	.64	.78
F. T_T, h	18.0*	3.7	1.35	.84
5. T_E/T_T	.11	.47	1.07	1.31

BLODGETT CREEK - PARALLEL

1. $Q = 11.7\ ft^3/s$; $\bar{v} = 0.43\ ft/s$; pH = 8.0

2. Distance, ft	12,500	10,000	7,500	8,000
3. A. T_L, h	8.1	6.5	4.8	5.2
B. T_E, h	2.40	1.97	1.53	1.60
4. A. C_u, p/m ft^3/lb s	1.55	1.85	2.20	2.10
B. pounds NH_3	76.0	76.0	76.0	76.0
C. C_p, p/m	10.1	12.0	14.3	13.6
D. C_E, p/m	8.36	9.96	11.9	11.3
E. C_{Eu}, p/m	.44	.52	.63	.60
F. T_T, h	>100.0*	4.6	1.3	1.6
5. T_E/T_T	<.024	.43	1.2	1.0

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*T_T values are drawn from figure 4, based on 50 percent mortality conditions.

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VAN METER, WAYNE P., and CHARLES E. HARDY
1975. Predicting effects on fish of fire retardants in streams. USDA For. Serv. Res. Pap. INT-166, 16 p., illus. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

Reports a first attempt to provide a computation system that will permit a rapid estimate of the amount of hazard to game fish caused by release of fire retardant chemical into streams. Field measurements necessary for application of the system are (1) the amount of retardant (pounds, nitrogen, calculated as NH_3) that enters a stream and (2) the discharge rate and average velocity of the stream, both measured at or near the point of retardant introduction. The result is an estimate of the time, or distance, necessary to allow dilution of the pollutant by shear and turbulent mixing to produce nonlethal conditions.

OXFORD: 432.3, 843.1.
KEYWORDS: aerial fire suppression, fire retardant chemicals, hydrology, fish toxicology, fire management, dye studies.

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*T_T

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)

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